French Engineers and the Machinery of Society: X-Crise and the Development of the first Macroeconomic Models in the Nineteen Thirties

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Abstract

The purpose of this article is to highlight the originality of X-Crise, an Ecole Polytechnique association formed in nineteen thirties' France. Firstly il analyses the factors leading the French engineers to look collectively, for the first time of their history, at the big politico-economic problems of their epoch. Two factors seem particularly relevant on this matter : their epistemology and value system on one hand, and their perception of the theoretical and political impotence at that time on the other hand.

Secondly this paper presents the main original theoretical elements that arose from the group's deliberations. Among them, it exposes the Guillaume brothers' macroeconomic model [1932], one of the very first macroeconomic model produced in France, and Potron's first application to economics of Perron-Frobenius's theorem (Potron [1911] and [1935]).

Keywords : French Engineers - Macroeconomic models - Pragmatism - Mechanics - Perron-Frobenius's theorem

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X-Crise,[1] an Ecole Polytechnique association whose acronym originally stood for "Centre de Renseignements et d'Informations Sociales et Economiques" before it became the "Centre Polytechnicien d'études économiques", was formed in 1931 by Bardet, Loizillon and Nicoletis. Its purpose was to think about the causes and possible solutions to the world economic crisis. From a membership of about twenty Polytechniciens in October 1931 it grew to almost 500 members by May 1933 and reached close to 2,000 (Polytechniciens and others) in 1939, when the association ceased to exist (Brun 1982, 19-35). As a think tank whose aim was to be open, tolerant and scientific, X-Crise brought together liberals like Colson, Michel and Rueff, socialists like Nicoletis, Moch, Bloch and Platrier and centrists such as Bardet, Detoeuf and Loizillon.

Our purpose here is to underline the originality of this intellectual move in nineteen thirties' France. What could have led these Polytechniciens to form a think tank on the crisis at that time? And what sets them apart from their French contemporaries from a theoretical point of view? By looking at these two questions in order, we will first try to shed some light on how research worked in France in the nineteen thirties. Then we will present one of the first macroeconomic models discussed by X-Crise at that time: the Guillaume brothers' model, and then turn to the first use, in french economic thought, of matrix calculus, differential equations and Frobenius's theorem.

1. Why X-Crise?

We can identify several reasons why a group like X-Crise was formed. The first is related to context: many factors - economic, discursive and institutional - supplied the springboard that launched X-Crise. The second stems from the value system and the dominant epistemology of the Polytechniciens of that period.

1.1. The Context

X-Crise was born, in France, in a very specific historical, economic and political context. In fact, the thirties represent a period when everything was being called into question due to the world crisis (Etner 1978, 97-107). X-Crise shared in this general questioning. We can identify four main factors likely to have prompted the Polytechniciens to take action on the economic problems of their time.

THE ROLE OF TECHNICAL PROGRESS IN THE CRISIS

Technical progress was the most important of these factors. In the thirties it was seen as the cause of the world's wealth but also of the general drop in wholesale prices which began in 1920 and of unemployment. The Recession and the crisis were attributed to overequipment and overproduction[2]. Everyone thought that a overextended economy discouraged sales and that machines were supplanting the workforce.

The engineers saw this type of analysis as a kind of indictment. The technical progress that they had created was not bringing hoped for happiness but, on the contrary, unemployment and economic stagnation. Thus, they could not remain indifferent to this thesis nor consequently, could they take a passive role in relation to the economic situation. Having till then only been interested in practical, technical problems, they now had to apply their knowledge to finding an answer to the crisis, by moving into the economic domain (Etner 1978, 111; Ullmo 1982, 273). Therefore, one of the central themes of the X-Crise Polytechniciens' work from the beginning was to show that technical progress could not be the

real cause of the economic and social problems of the day. This was borne out in the study, "Réflexions sur six mois de travaux" (Bardet 1932)[3]:

> "are we witnessing a situation where the adaptation of the individual is simply not in tune with the material possibilities progress is opening up for him, and will it be enough to fit the existing system with a regulator? Or has the problem been tackled from the wrong angle, and should we, on the contrary, adapt man's work to the individual's needs, leaving a supreme authority whatever its nature (political or economic) with the task of systematically ensuring an equilibrium?" (*idem*, 48).

Thus the interpretation of the world crisis current at that time seems to have led the French engineers to look collectively, for the first time in their history, at the big politico-economic problems of their time. The limited response to the appeal by the three founders of X-Crise in October 1931 could be seen as negating this hypothesis. It seems to us, on the contrary, that X-Crise's rapidly growing success, validates the hypothesis.

ECONOMIC PLANNING (*PLANISME*)

The second factor in many Polytechniciens' new fascination with the economic problems of their time was based on economic planning (*Planisme*). The content of this doctrine, characteristic of the ideology of the thirties in France, varied according to the political group that wished to appropriate it at the time (Amoyal 1974, 137-144). Nevertheless, it seems to have been accepted that the principal idea of economic planning was interventionism intended to rationalise economic activity "by means of a series of regulating interventions which [...] would lead it towards carrying out a plan set by a commonly recognised authority" (De Man 1932, 5). If this definition seems imprecise, it is because interventionism, and especially rationalism, a theme the engineers were particularly sensitive

to, could take on many meanings depending on who used them. Originally used to describe the organisation of production within a company and instituted by Taylor, Fayol and Ford, rationalisation, when extended to the field of economic activity on the whole, referred more to the idea of "co-ordination of economic activity" by the State (Etner 1987, 242).

From the beginning the X-Crise Polytechniciens were interested - and this is one of the group's most original features - in the theme of economic planning as well as the related themes of interventionism and rationalisation[4]. In fact, as Bardet noted in the report on the Polytechniciens' first six months of deliberations:

> "[we] must intervene, not only because it is our duty as human beings, but out of social necessity. We must intervene scientifically, generously, without prejudice and with altruism. No-one, when he sees that the world he lives in is slowly being stifled, has the right to adopt a "laisser faire" attitude, for, as Gœthe said, death is the only natural balance we achieve through lack of will" (Bardet 1932, 47).

The influence economic planning had on the Polytechniciens can be explained by the Saint-Simonian tradition which they held to (Etner 1978, 110)[5]. At the very least it is clear that the idea of intervening in economic life to ensure the continuation of a rationality that would otherwise be lost, echoed the function and purpose French engineers had always had in the technical field. Moreover, this influence was even more significant when put into the context, discussed earlier, of the French engineers' reaction to the interpretation of the crisis current during the thirties. Associated with the themes of the rationalisation of economic activity, economic planning, in fact, attracted the engineers' "modernist minds" (*idem*., 104). In particular, it responded to the fascination with America where Taylorism and later Fordism were instituted and rationalism resulted in a new social policy. It also responded to the pragmatic philosophy that typified, as we will show later, the French Polytechnic engineers' philosophy of action during the thirties. Thus, for Branger, "economic planning is [...] a

pragmatic mindset, enemy of any systemisation" (Branger 1935, 12). Finally, it suggested a conception of society as an "economic machine" with the State holding the "levers" that controlled the "wheels" of its structure (Amoyal 1974, 140), a concept that the engineers could not ignore.

A DOCTRINAL DEBATE

The third factor that explains the formation of X-Crise arose no doubt from the perception the engineers had of the doctrinal nature of economic debates in France. One of the characteristics of the intellectual context of the thirties in France was the lack of a theory on the crisis. This theoretical vacuum made the Polytechniciens all the more uncomfortable when they were confronted with a crisis situation, for all they saw was a doctrinal conflict between the liberals and the interventionists[6], which included the theory of economic planning. When, in 1937, Ullmo reproached Pirou with the vagueness of his definitions, he upheld this diagnosis: "all the post-war economic debates have revolved around mistakes and misunderstandings of definitions" (Ullmo 1937, 8). Also, confronted with the doctrinal nature of the debates, the Polytechniciens were to adopt the goal of "creating a «meeting place» for dispassionate discussion and objective, disinterested examination of the problems of the modern world, set out and treated according to the scientific method [they had been] trained in" (Nicoletis 1967, 19). In fact, Bardet wrote:

> "let us not limit ourselves to stating well defined dogmas, such as the liberal dogma or the socialist dogma. We will only reach a sterile impasse. Let us rather highlight the differences and similarities that result from a comparison of the procedures they advocate. And perhaps this impartial examination will allow us to identify more

clearly the remedies that can be applied practically and that will be inspired only by the common good" (Bardet 1931, 116-117).

But this third factor could not alone have caused the creation of a group of Polytechniciens such as X-Crise.

EDUCATION AND INSTITUTIONS

The fourth factor is institutional in nature. The primary one was the teaching of economics in France, but the Ecole Polytechnique's policy of motivation during that period also played a major role. We will not address the first point here as it has already been the subject of very comprehensive works (Etner 1978; Picory 1989; Zylberberg 1990). Let us just retain the idea that the teaching of economics in France is a fairly recent addition in law faculties, which explains in part the often doctrinal nature (mentioned above) of political economy in France (Pirou 1937, 29).

The second point is based on the fact that the school went through an institutional legitimacy crisis in the twenties. This factor probably played a part in the strong mobilisation of the Polytechniciens around economic questions in the thirties. The economic crisis reawakened the Polytechniciens' feeling of loss of social legitimacy. In fact, during the twenties the school had suffered a crisis of legitimacy which, through government bills, threatened, it with disappearance (le Chatelier 1924, 6). Le Chatelier, following Colson, repeated in 1924: "an aristocracy like ours is condemned to disappear when it stops providing services to the community that, in the past, earned it public favour" (*idem.*). So the Ecole had to react in order to survive. This it did by calling on its members to create study groups on the social sciences (*ibid*., 13) in order to get more involved in the organisation of the country's economic and social life:

> "By better organising our efforts, France could double her wealth and power. That is a goal worthy of the Ecole Polytechnique's concern" (*Ibid.*, 20*).*

This call had prepared them for a form of reaction like X-Crise, even if there had been no response during the twenties[7]. The economic crisis was the mechanism that set off this reaction, as we can see from how quickly the Polytechniciens' movement grew. Their feeling of non-legitimacy was reactivated by the crisis, all the more so since unemployment was seen as a result of technical progress (see above)[8]. Thus, the formation of X-Crise marked the Polytechniciens' desire to recapture the social legitimacy that was being contested.

1.2. Values and epistemology

Apart from the external factors prevailing at the formation of X-Crise the characteristics peculiar to the Polytechniciens also played a part. We will only discuss the two principal ones: their value system and their epistemology.

THE POLYTECHNICIENS' VALUE SYSTEM

X-Crise would not have been able to be formed without the Polytechniciens' value system. The sense that they embodied the republican aristocracy was their fundamental value (Nicoletis 1967, 19) from which, indeed, arose the form taken by their collective reaction. The habit of making up groups around specific fields of interest and the maintenance of an "esprit de corps" outside of the school per se explains, to a considerable extent, the founding of X-Crise. This value system also accounted for the open-mindedness[9] and scientific focus of this group. Their sense of elitism (Bardet 1931, 47), in fact, encouraged them to follow scientific progress closely:

> "The sciences are in a total state of ferment. To ignore this movement and persist in a disdainful immobility would be equivalent to suicide" (Le Chatelier 1924, 21).

This was probably one of the factors that would lead the group to become interested in the emergence of econometrics. The need to follow the latest developments in science sometimes brought them up against theories that they were reluctant to teach. Their attitude towards Einstein's physics, in fact reveals a conflict of values. Le Chatelier, in his speech on January 20, 1924, gave the Polytechniciens the following warning:

> "Fashion and snobbery are, I fear, tending to draw us in a retrograde direction. Time, obeying Einsteinian suggestions, seems to be going backwards taking us back towards the Middle Ages. Inaccurate and unverifiable hypotheses are praised to the skies, experience is disdained and judged at the very most fit for bricklayers". Modern science, using the methods of a poker player, contents itself with outspoken assertions; reason is replaced by audacity and general improvement of the mind is looked down on. So let us deny secular traditions, abandon the path traced by brilliant scholars: Pascal, Lavoisier, Sadi Carnot, Ampère, Fresnel who constructed Science on absolutely rigorous experiments and reasoning. Could the Ecole Polytechnique, proud of its past, not try to raise the flag of clarity, prediction and method. I hope so with all my heart" (*idem.*, 22).

In the face of the threat of new physics driven by Einstein which challenged the dogma of Newtonian physics the Polytechniciens were to bring to the fore what was their true direction in the sciences: experience.

Constantly reaffirmed, particularly in a crisis situation, experiment and measurement, the true conditions for validating a scientific statement, embodied the Polytechniciens' principal epistemological values. Thus, in view of this value system, the welcome given by the Polytechniciens to the pragmatic American epistemology of the thirties is no surprise.

THE ENGINEERS' PRAGMATISM

The operationalist form of pragmatism, permeated X-Crise's epistemological ideas[10]. Introduced to France by Alexis Carrel and to X-Crise by Guillaume[11], the American, Bridgman's operationalism rested above all, on the pragmatic principle formulated by Peirce: "Every theoretical distinction should lead to a difference in practice" (quoted by Lapoujade 1997, 9). We can see at once the main reason why the engineers were favourable to this epistemology. According to this pragmatic principle, every idea engenders practical consequences (*idem.*, 47) and must thus be evaluated according to them. Since the engineers had to resolve applied problems they wished to provide themselves with theories that could guide their actions. Pragmatism gave them an appropriate epistemological framework, particularly since this epistemology was not just a means of evaluating ideas, it also helped

> "to create the ideas that can serve either action or thought. So it becomes a creative tool. *How ideas are formed and what we do with ideas* these are the two axes of the pragmatic method" (*ibid.*, 11).

Thus pragmatism provided the engineers with an epistemological framework that allowed them to state "operational" concepts, to use "small models" and measure phenomena with precision in order to adjust the action.

The operationalist version of Bridgman's pragmatism stipulated that concepts had to refer to concrete operations. In *The Logic of Modern Physics* 1927, Bridgman used Einstein's theory of relativity to propose a new way of defining an object (Machlup 1960, 159). Rather than defining a concept through the essential characteristics we attribute to the corresponding object, Bridgman proposed defining it through a series of physical operations carried out by an observer to prove the presence of the object relative to the concept. In Guillaume's words, "a

concept is not clear, indeed has no meaning unless it corresponds to an operation or a group of very specific operations, in other words, unless it forms an "operational" concept" (Guillaume 1937, 243). According to Bridgman a concept was only operational if it could be associated with a measurement. Moreover, it was on this basis that Guillaume rejected the "subjective" foundations of Walras and Pareto's theories, since ophelimity was not directly measurable (Guillaume 1932, 43). On the contrary, they observed mass behaviour, like fashion phenomena, which was literally produced *via* advertising by the big manufacturers. Mass consumption, because it was measurable, became an "objective" phenomenon, which then became one of their central models (*ibid*., 44).

In connection with this operationalist epistemology, one of the methods used by the engineers was founded on the creation of "small models". Here again, the Guillaumes were the most explicit[12]. For them, "it is clear that even building a model can only be based on operational concepts" (Guillaume 1937, 243). If not, the process of making models would have no meaning for the engineers because it would have no practical consequences on their action. The "small model" was a miniature representation of the real world (Guillaume 1932, 62), with the same structure. Just like a "small-scale model" it let an engineer experiment with the behaviour of a work before creating the life size version (Guillaume 1937, 242). These models had to be based on a minimum number of principles in order to ensure "economical thinking" (Guillaume 1932, 62), in the words of the physicist Mach whose convert Bridgman had become[13]. Thus "the true laws imposed by this structure" could be discovered and their coherence ensured by mathematics. The primary objective of "rational economics" became the discovery of economic laws, of the rationality of the system and of its imbalances (Guillaume 1932; Pourquié 1936) the ideal being to "create an *Economique rationnelle* similar to a body of doctrines such as Rational Mechanics" (Guillaume 1937, 3). Thanks to these operational

models and the rigorous deductions they made possible, "[i]t was to mathematics alone that we turned for the answers to the economist's questions " (*idem*, 244).

The operational models thus made it possible to measure economic phenomena (*ibid*., 243, Ullmo 1937, p. 10). The question of measurement explains the fundamental role accounting played in the Guillaumes' theoretical project, a role that would create a perception of their project as a veritable outline of national accountancy (Ullmo 1982, 276). More generally, it brought out the engineers' interest in econometrics[14] giving them the indispensable measurement that went with the creation of operational models. So, for the engineers measurements and predictions were the two essential properties for making the models not only "operational" but also "operative" on economic reality.

Thus pragmatism constituted an epistemology that coincided perfectly with the engineers' aspirations. It allowed them to produce concepts that were "useful" (Lapoujade 1997, 60) and that furthered the progress of societies, as the physicist Bohr's theories had done (Guillaume 1932, 63), without concomitant negative consequences[15]. From the pragmatic point of view, economic theory should be equipped with concepts that establish a diagnosis of the causes of the economic crisis (Chait 1938, 9), in order to guide the politicians in their fight against its manifestations (Moch 1933-4, I: 25). Finally, we note that this epistemology also brought into evidence two types of studies carried out by X-Crise: the development of general models, on the one hand (Guillaume 1932; Moch 1933-4), and on the other hand, the study of specific questions (gold, devaluation, debt, inflation and production costs, reduction in working hours, income distribution ...). For our purposes in this discussion we will single out the first type which comes under the generic term of "rational economics". In fact, these models best demonstrate the originality, in the France of the thirties, of the Polytechniciens' approach to the economic problems: an attempt to forget earlier theories in order to look with

a "new"[16], "objective" and "scientific" eye at the problems to be resolved, a characteristic central to pragmatism (Nicoletis 1967, 19).

2. Some original theories from X-Crise

Now that we have discussed the factors leading to the formation of X-Crise, we will look at the original theoretical elements that arose from the group's deliberations. Also, even if its ambition was to arm itself with a range of weapons to fight the crisis, we will limit our discussion to the theoretical models developed to make a diagnosis of the crisis. In fact, the main model that came under theoretical debate was the Guillaume brother's one. This model was, in fact, discussed from the first publication of the *Bulletin du Centre Polytechnicien d'Etudes Economiques* to the last ones. Moreover, the first number of the *bulletin* began with Boris, the chairman of the meeting's speech which was followed by an overview of their theses:

> "The meetings of January 16 and 20, 1933, were devoted to a talk by Mr. George and Mr. Edouard Guillaume on "The foundations of Rational Economics". Many of our friends made a point of attending these meetings during which they were able to appreciate the value of a completely new and very clearly presented theory. The mathematical language used by the speakers during the first part of their lecture couldn't help but make it easy to understand the principles and let the audience become familiar with this type of research for exploring economic phenomena. The second part of the lecture, could only convince all those present how easy this technique made it to clarify the mass of present facts and, in particular, to see the regular role of gold on exchanges at a world level. Mr. George and Mr. Edouard Guillaume, who had won their audience over with their courtesy and the modesty with

> which they dealt with these fascinating topics, were enthusiastically applauded and congratulated for the success of their work which, from now on, takes its place in the history of economic theories, and furnishes us with a very fruitful investigation method" (Boris 1933, 3).

Thus, presenting X-Crise's theoretical research meant first and foremost, discussing the main points of the Guillaume model that fascinated the Polytechniciens. But it also means examining the research methods used by the latter in developing their theoretical models. These are the two points we will address.

2.1. The Guillaume brothers' rational economics

For the Guillaume brothers, the creation of a model had to be based on axioms that were sufficiently solid to be operational[17]. This was precisely the flaw in the doctrines of "Classical Economics". In fact, they:

> "make up a sort of agglomerate rather than a scientific monument. The latter would require, rather, a supporting framework, upon which the various parts would be strongly built. In the absence of such a structure we are never sure, in political economics, of stating truths which are not contradictory. [...] Moreover, don't the countless, more or less contradictory opinions that have been expressed by the economists, during the present crisis (1929-1936), show us that the doctrines of Classical Economics leave us in a state of impotence? That is what has led us to wipe the slate clean and try to construct an edifice resembling the physical sciences, whose fecundity is revealed in the admirable rapid expansion of modern industry" (Guillaume 1937, 1-3).

In expressing themselves thus, the Guillaume brothers couldn't have explained more clearly their approach in founding rational economics. In order to propose scientifically established solutions to get out of the economic crisis, they proposed arming themselves with real axiomatics which would be "operational" and "fecund".

OPERATIONAL AXIOMS AND ACCOUNTING CONCEPTS

Operationalism led the Guillaume brothers to adopt operational concepts, whose references were observable and measurable phenomena. What we "observe" at the level of "economic cells" is the financial year: balance sheet, profit margin etc. (Guillaume 1932, 179). Thus, the Guillaume brothers naturally turned their attention to accounting[18].

The first principle retained by the Guillaume brothers was the "law of conservation of commodities flow". It refers to all possible allocations for a given flow of commodities produced. This law

> "means nothing more, in industrial accounting, than the warehouseman's obligation to check his inventory, using, on the one hand, what remains in the warehouse, and on the other hand, the "shipment forms" he signed when he delivered the merchandise" (Guillaume 1937, 48).

For example, for merchandise A, it is expressed in the following relationship (Guillaume 1932, 82):

$$[1] \qquad \dot{q}_A = \sum_{H=A}^{H=N} \dot{q}_A^H$$

The second fundamental principle also rests on accounting. This is the "law of conservation of value flows", presented in the form of an axiom which expresses a necessary equality between

the "value flow" of the production of goods, and the sum of the flow of the factors, expressed in values necessary for the production of those goods.

> "When we try to enter all the relationships that determine the production costs, we are hit by the realisation that, when all is said and done, we are expressing nothing else than a «law of conservation» analogous to the principles that form the basis of the physical sciences. A similar principle exists in double entry bookkeeping. In fact, we know this requires that, for every entry there is a corresponding contra entry and that the inventory corresponds to the items posted. Based on that rule we postulate the principle we have called the «law of value conservation»"(*idem*, 3-4).

As a formula, for commodity A, we have

$$[2] \qquad a\dot{q}_A = \sum_{\substack{h=a \\ H=A}}^{\substack{H=N \\ h=n}} h\dot{q}_H^A$$

where the "value flow" of commodity A per unit of time is equal to the sum of the "flows of values assignable to all the commodities that enter into the production of A" (Guillaume 1937, 254).

We understand here that these two principles or "fundamental principles" (Guillaume 1932, 85), prefigured in matrix form the national accounting system that was to prevail in France.

For Guillaume, these principles were supposed to provide the key to resolving the problem of the crisis. They made it possible to "look for *where* a value that appears and disappears *goes*" by doing the accounting for all individuals (Guillaume 1937, 43). For "we must seek the trace of the mechanisms of this leak in the accounting for all individuals" (Constant 1937, 33). In fact, it was at this level that the stalling symptomatic of the crisis

appeared and not between two individuals one of whom had made a good bargain and the other a bad one.

A MACROECONOMIC APPROACH

Through the use of an accounting approach involving the law of value conservation a macroeconomic point of view could be developed. In fact, by basing the key concepts of the theory they were developing on accounting for individual cells, the Guillaume brothers made it possible to build macroscopic concepts through simple aggregation to arrive at "general accounting" (Guillaume 1932, 3). This macroeconomic approach is evident in Guillaume's analysis at two levels.

The macroeconomic dimension appeared on a first level in their conception of the phenomena of consumption and production. Criticising the ophelimity approach based on the "tastes and desires of each person" the Guillaume brothers developed the idea of an "implacable economic determinism" leading to the definition of "average consumption rations for the greatest number of everyday commodities"[19]. From there they determined "approximately how many grams of bread, meat, eggs, fruit etc. 'the average individual' consumed daily, how many pairs of shoes, metres of sheeting, cloth etc; he used on average per year", without giving any thought to such characteristics of microeconomics as the individual utility function, indifference curves, etc. (Guillaume 1937, 153). The same concept was applied to production characterised by mass production standardised goods sold through advertising (Guillaume 1932, 44).

The macroeconomic dimension also appears in their idea of the circuit that spread rapidly through X-Crise (Constant 1937, 34). This idea was based on the example of China,

the only country to understand the principle of the perpetual *circulus* where "nothing is lost" (Guillaume 1932, 66)[20].

Although this point of view certainly was not new, it nevertheless, made it possible to introduce a macroeconomic approach to the crisis. In fact, this cyclical representation led Guillaume to see the crisis as a leak in the economic system. The crisis was characterised by the existence "of wealth on the one hand and the impossibility of benefiting from it on the other hand" which resulted from a "failure in buying power" (Guillaume 1937, 52)[21]. These leaks, which until then had been inconceivable, were brought out, as we shall see, by the theoretical introduction of time and money into their model.

THE GUILLAUMES' MACROECONOMIC MODEL

The Guillaumes' macroeconomic model rests on a series of crucial hypotheses and concepts[22].

1/ First of all, the Guillaumes based their reasoning on the gold standard system in effect at the time. The volume of liquidity had to be in proportion to the available gold reserve. This introduced a strong constraint which weighed heavily on their theory about the crisis.

2/ The second hypothesis, introduced by the Guillaumes, was demographic. The population grows in each period in proportion to the ε rate in conformity with the equation

[3] $n = {}_0n\, e^{\varepsilon t}$ (Guillaume 1932, p. 107).

Thus the growth of this population is considered as exponential. Insofar as this population's consumption is determined by "average rations" the volume of commodities consumed should grow proportionately.

3/ Starting from their accounting approach, the Guillaume brothers considered "a full financial year during which a full cycle of all production consumption has been completed" as a "unit of time" (Guillaume 1937, 50). During this cycle, flows of commodities are produced and consumed. If the population grows exponentially production must also grow exponentially. Thus, the amount of a given commodity produced during a given financial year is expressed as the following equation (*idem*, 316):

$$[4] \qquad q_H = {}_0q_H \bullet e^{\lambda_H t} .$$

The quantity produced q_H, at the end of t the accounting period, depends on the initial quantity of the commodity available ${}_0q_H$ and its production at an average annual rate of λ_H. Then the Guillaumes deduced the concept of "speed of production" (and, respectively, that of "speed of acquisition"), that is the derivative relative to t (or the differential) of the equation [4]:

$$[5] \qquad \dot{q}_H = {}_0q_H \cdot \lambda_H \cdot e^{(\lambda_H - \varepsilon)t} .$$

Thus the quantity produced during a period depends jointly on the volume of labour used (or "capacity factor ") and the speed of production (also called "action factor") (Guillaume 1932, 107). There are then two possible solutions to increase productivity: increase the "capacity factor" (number of workers) or the "action factor" (hourly productivity) (Guillaume 1937, 285). The Guillaumes then introduced the idea of "rationalisation" or "speed of growth of the action factor" (Guillaume 1932, 113; 1937, 291), that is the second derivative of the equation [4]:

$$[6] \qquad \ddot{q}_H = {}_0q_H \cdot \lambda_H (\lambda_H - \varepsilon) \cdot e^{(\lambda_H - \varepsilon)t} .$$

This rationalisation can be measured when we calculate the relationship of the two derivatives. We obtain the "rationalisation rate" τ, that is

$$[7] \qquad \tau = \frac{\ddot{q}_H}{\dot{q}_H} = \lambda_{H} - \varepsilon.$$

ε being the rate of population growth and λ_H being the rate of growth in production (*idem*).

4/ The Guillaumes then made the hypothesis that rationalisation rates differ according to sectors of activity[23]. They put forward two reasons for this phenomenon. The first is related to the rate at which new techniques are introduced, these rates varying according to the sectors of activity. The second comes from the unequal effects of the introduction of technical progress on production rates in different branches and sectors of activity.

5/ Finally, a theory of labour value is implied in the Guillaume brothers' accounting. They, in fact, assumed that the value of a commodity depended on the amount of work required to produce that commodity. Any decrease in the amount of work involved in a given article relative to another should therefore translate into a drop in the relative value of the given article, a relative drop in the price of a product being obtained in the sector with the greatest rate of rationalisation.

But, the Guillaume brothers explained, this drop in price was effectively blocked by two factors: on the one hand, the desire for immediate possession of merchandise, mass produced thanks to the rationalisation of production, and, on the other hand, the inflexibility of prices in the short term. As a result, adjustment occurred, as with Keynes, through quantities and not prices. It remained to be understood how this desire could be satisfied without adjusting prices and with a given gold reserve.

A CRISIS THEORY

The answer to this question was found in the introduction of credit. For the Guillaumes, credit was the introduction into a given financial year, of purchasing power

which, otherwise, could only have appeared in a later accounting year. Thanks to this additional purchasing power obtained through credit, it became possible to consume without waiting for a drop in prices. In fact, credit allowed those who used it to consume more value than they produced. But in so doing, credit upset the law of value conservation.

The Guillaume brothers showed that, in fact, the introduction of credit didn't only block the mechanism of relative price drop, it also disturbed the workings of Say's law by provoking "legal-economic leaks". These leaks create imbalances that are characteristic of a "general crisis" where "exchanges are blocked" (Guillaume 1937, 124). In fact, the introduction of credit creates a situation where

> "the sum of the statement of profits and losses is different from zero for the entire community. A certain number of individuals make profits (or losses) without a compensatory effect from this situation on the others" (*idem*., 129).

The law of conservation of value flows is thus invalidated. The reason for this is simple:

> "a promise means introducing into an accounting year what should be in another one: it is an attempt to gain time. In reality, it loses time because it means producing less value than one consumes. In these conditions, one should ask how a producer who is behind and in debt can catch up the lost time. We shall see that, at the macroscopic level, it is impossible" (*ibid.*).

The Guillaume brothers put forward two essential reasons.

In order to pay back their debts the "late payers" would have to create a higher value in the following financial year by rationalising their production at a higher rate than the one current in society. Thus they would produce a value equal to the loan plus interest of the debt (supposing that the sale of their products was made partly with the help of credit). Attaining such a rationalisation rate

> "is very difficult, because production speeds do not depend on human whim but only on the degree of technical progress achieved. Everyone is going as fast as possible, that is, reducing their production costs as much as they can. Yet, it is difficult to speed up some productivity, or even to stop it from slowing down, as with those subject to *the law of diminishing returns*. If, in practical terms, it is almost impossible for acceleration factors to intervene, we must conclude that world indebtedness is an irreversible state" (*ibid*., 136).

In addition, in order to repay his debt, each individual must sell more than he spends. Such a situation, if we take into account the law of value conservation, freezes exchanges unless further debt is incurred. Failing that, the stalled situation translates into such a relative drop in prices that the sale prices become less than the production costs leading to "operating losses", bankruptcies (since the debtors can't sell, they can't repay their debts and thus drag the banks into bankruptcy with them) (*ibid*., 140) as well as - and we should note this idea for it was not very well known at the time - a situation of involuntary unemployment linked to the reduction in activity (with the debtors stopping production since they couldn't buy anything more). In other words, society is either in a state of perpetual debt, creating "economic euphoria" or in a state of generalised crisis which ends with the interruption of the issuing of credit (*ibid.*).

Since the Guillaume brothers used the gold standard system as the basis of their reasoning, they concluded that society was tending towards a generalised crisis. In fact, indebtedness corresponds to a pseudo-creation of gold at a very low price. At that price, only the most productive mines can be active. Therefore, gold production tends to decrease. In order to maintain gold parity, gold production should be rising in proportion to credit growth (*ibid*., 148 and 152). This distortion implies a curb on the issuing of loans, which inescapably provokes the crisis.

From this ensues, according to Guillaume, the only solution to this phenomenon: an increase in gold production according to ratios known through the creation of an international institute of economics. Thus, the inevitable

> "State interventionism, a minimum of which we are always subject to, will become more efficient when it is based on the knowledge of phenomena, in order to encourage their natural development instead of thwarting it as it is sometimes accused of doing" (Guillaume 1932, 229).

Thus, the Guillaume model introduced elements that were completely original for their period in France, showing, moreover, that the Polytechniciens had been able to accept Keynes's theories[24]. Guillaume's last remark shows, nevertheless, that their ideas, innovative as they were, were in no way revolutionary. Their arguments were still embedded in the logic of Say's law, and their ideas were in keeping with the liberal point of view.

2.2. Mathematics and experiments

The engineers were stamped with the classical physics model and would try to transpose its methods to the economy. So now let us look at the type of mathematics the members of X-Crise used in economics, the role they gave them, and the test processes they set up to prove their theories.

THE MATHEMATICS USED: POTRON'S EXCEPTION

The mathematics used by the engineers in the models for their investigations of economic phenomena remained fairly close to those of the founders of mathematical economics. For if Guillaume and Moch's models used differential equations almost

systematically[25], these did not let them study the dynamic development of systems mathematically. In the absence of an adequate mathematical theory, they settled for using exponentials and integrals to describe the movement of variables. Therefore, X-Crise would not be the spawning ground of a new mathematics to analyse economic phenomena.

Nevertheless, we must note the exception here. This was Father Potron's first application to economics in France of Frobenius's theorem[26]. A professor at the Institut Catholique, unfamiliar with economic theories, Father Potron is best known for his mathematical works on groups' theory[27].

In "On Certain Conditions of Economic Equilibrium" which appeared in the July-August 1935 *Bulletin*, Potron addressed the following to Gibrat.

> "At the meeting of last February 22 at the C.P.E.E. I spoke to you about a matrix of supply and demand, considered by Frisch. There is another, very interesting matrix, that I believe I have been the first to consider, at least in its application to economic problems" (Potron 1935, p. 62)[28].

He was referring to "Frobenius's theorems (stated and proved in 1909) on *matrixes* or *linear substitutions* with *positive* coefficients" (Potron 1935, 57). By applying this theorem to economics, Potron intended to show that

> "[t]he probability of coming upon a satisfactory production, price and salary system by chance is so slight that finding such a system is more or less impossible" (Potron 1935, 65).

To show this, he proposed using matrix calculus to study what we would call today the conditions of existence of an equilibrium. First he raises the question of the theoretical possibility of such an equilibrium (Potron 1935, 64), before tackling the question of its stability when technical progress and investment disturb this state (*idem*.).

With reference to the first point, he proposed, after presenting the variables and all the relationships that give the economy its structure, to organise them in the form of two matrix systems (*ibid.*, 63). The first simply consisted of a group of unknowns - the quantities produced d_i - which, combined with matrix C_{ki} of all consumption necessary for production (intermediate consumption, time worked (hours), final consumption per person, legal maximum number of working hours per person), gave surplus F_i (representing a linear combination of "non-workers", number of non-worked hours - "unemployment" - and "overproduction" which implicitly covers investment and stock) :

$$(1) \qquad d_i - \sum_k C_{ki} d_k = F_i \ .$$

Here we should point out Potron's originality in explicitly taking into account the role played by the unemployed in the economic system through their consumption.

The second system of equations also only contains one group of unknowns, prices a_i, which depended on matrix C'_{ik} (representing the matrix transpose C_{ik}) and matrix B_i (linear combination of "business profits" and "workers' savings ") :

$$(2) \qquad a_i - \sum_k C'_{ik} \, a_k = B_i$$

Thus Potron arrived at a matrix representation of what he called a social-economic state:

> "one can say that the body of values attributed to these diverse symbols are characteristic of a given social-economic state. Such a state will be satisfactory and stable if the following conditions are met" (*ibid*., 62).

Potron then went on to apply Frobenius's theorems to these positive matrixes to see if a "satisfactory" organisation of production could be obtained, and to establish a "satisfactory price and salary system".

To do this, he first had to discuss the "coefficients" in the matrixes, as well as their variability. This discussion proved astonishing, for in it Potron pointed out the role organisation plays in a company's production process, as well as the conventional nature of prices and salaries.

> "The possible effect of human will on various coefficients varies greatly according to their category. The c_{ik} [intermediate consumption coefficients] and t_{ih} [hourly work volume] are controlled by manufacturing procedures and the organisation of various enterprises. We can influence them with new inventions and through "rationalisation", but that influence will always be quite slow and, on the whole, fairly limited. On the contrary, prices, salaries and the number of personnel are not imposed by any *physical* necessity. They are the result of *conventions* which are, at least theoretically, *free*. They can be modified quickly" (*ibid*., 63).

These characteristics were to play a decisive role in the potential achievement of a satisfactory resource allocation system. Potron's study of coefficients led him to assert that matrix C_{ik} of intermediate consumption and its transpose are square matrixes, and, more generally, that all the matrixes are positive.

These characteristics meant that he was one of the first to apply a "pure mathematical theorem" to economics. In applying it to the matrix of intermediate consumption, Potron noted that this matrix's characteristics affected the whole of economic organisation.

> "Thus everything depends on the characteristic root of table $\| C_{ki} \|$. If it is <1, it is theoretically possible to organise production in a satisfactory manner, which necessarily entails a certain amount of overproduction, unemployment and non-workers. Assuming such an organisation, it is theoretically possible to establish a satisfactory system of prices and salaries, that involves some profits, and, for the

> workers, some savings resulting from the *actual salary received* exceeding the cost of living" (Potron 1935, 64).

But Potron did not indicate if this "satisfactory system" would be Pareto-optimal and if it could actually be achieved. Moreover, this state of the economy depended on factors - like technical production characteristics - that are assumed to be constant.

Potron showed that, as soon as technical progress modified these parameters, the chances of obtaining a satisfactory system diminished greatly.

> "This in part explains why technical progress, which should provide man with more well being for less overall work, is often, on the contrary, a cause of misfortune and ruin" (*idem.*).

In fact, the main reason was the lack of laws regulating the economic system.

> "Each business P_i knows its own c_{ik} [intermediate consumption] and t_{ih} [hours of work required for production]. But there is nobody to formulate and solve the system [1] [which divides the quantities produced into intermediate consumption, final consumption and "surplus"]. Everyone takes his d_i [quantities produced] haphazardly, and we are completely surprised to have a huge F_i ["surpluses"] which implies serious unemployment or heavy overproduction, or, on the contrary we have negative F_i, which is no less disastrous" (*ibid.*).

Thus Potron came to the conclusion that, in the absence of a self-regulating mechanism, economic equilibrium is "improbable" even if it is logically possible.

THE ROLE OF MATHEMATICS

While Potron's approach demonstrated a key role played by mathematics in the investigation of economic phenomena, it was unusual for its time and for X-Crise[29]. Whether

for Guillaume or Moch, the role of equations was confined to creating economic arguments based on mathematically established relationships. While mathematics let them base themselves on precise definitions and non-contradictory logical relationships, which ordinary language doesn't allow, (Ullmo 1937, 10), far from being "the language [...] allowing [...] the exploration of economic phenomena" (Boris 1933, 3), the mathematics used by these authors served rather to find the effects of one variable on another, as well as its possible repercussions, in order to draw qualitative conclusions[30].

In keeping with this was the introduction of time into the equations. By indexing the variables with the temporal variable, Guillaume and Moch were not seeking to calculate the development of their mathematical systems mathematically. They merely gave a glimpse of the effects of a variation in time of one variable on another. Moch's analysis of the repercussions of a variation in salaries on the economic system reflects this, even though it does bring to mind Kahn's investment multiplier[31]. But it does not result in a mathematical evaluation of these effects, not to mention a quantitative evaluation of them.

> "Consequently, even though purely abstract equations allow us, a priori, to assume anything at all, we can be sure that the total value of salaries will grow more slowly than the total value of production. And we know that this is indeed the case" (Moch 1933-4, III: 20).

All these authors invoked, in one form or another, the argument "that it is not possible to solve, for the world of economics, the equations that would give the magnitudes defined above for all commodities produced" (Guillaume 1932, 79). Thus the engineers simply sought mathematical relationships that allowed them to structure their vision of economics. In spite of their undeniable interest in econometrics, they never tried to test their models using econometric procedures.

EMPIRICAL TESTS AND GRAPHS

The only "test procedures" used by X-Crise members are few graphs created by Guillaume on the one hand and Moch on the other hand.

Guillaume's procedure is the result of the introduction of time into economic analysis:

> "finally, to completely master all our equations, we thought of representing movements by means of graphs which we could call "*cinémogrammes*". These allow us to prove our theory experimentally" (Guillaume 1932, 4).

The programme, an ambitious one, brings to mind Moore's _synthetic economics": introducing time into economic analysis in order to create an empirical basis for one's laws. Unfortunately, when the programme was realised it fell short of its goal. In fact, as its name implies, the "*cinémogramme*" was simply the transposition of cinematographic principles to the dynamic representation of economic phenomena. Using the metaphor of a bird's flight as their basis, the Guillaume brothers wrote:

> "isn't the best way to study its flight to photograph it at fairly close intervals of time? [...] In other words, if there were no cinematography it would have to be invented for this circumstance. In short, we propose to represent every instant of economic life in its entirety, and compare the images thus obtained. Economic life is a complex whose principal factors we can represent, rather like a cartoon" (*idem*., 181).

In place of an instant photograph they proposed a series of graphs representing the balance at a given instant for an economic cell or a market, in which each component was represented by a rectangle proportionate to its importance in the balance. A time comparison of these graphs would make it possible to show the development of the phenomenon being studied (*ibid*., 186) and, possibly, to predict it (*ibid*., 189). Obviously, at no point, did such a representation of time enter into these graphs. It was the succession of these graphs that expressed the

movement and made it possible to understand the development of economic phenomena. Thus the Guillaumes, like all the others before Samuelson, came up against the theoretical problem of the mathematical analysis of dynamics. Finally, let us note that this type of representation did not allow for any empirical proof of economic theories. And indeed, the Guillaume brothers would not attempt this proof.

Moch's procedure was also reminiscent of Moore's procedures for estimating the supply and demand curves. It used Guillaume's "*cinémogramme*" to propose

> "the outline of a method that could allow us to interpret certain statistics and compare the theories and facts" (Moch 1933-4, III: 27).

This method tried to characterise the market and follow its development. For this it assumed that

> "market conditions, for a given product, can be characterised at a given moment, by the relative surplus (positive or negative) of production over consumption, and by the relative surplus (positive or negative) of the sale price over the cost price" (*idem.*, 28).

Therefore, we can put these successive market conditions on a diagram made up of two axes where the vertical axis is the percentage of profit (h) and the horizontal axis the percentage of overproduction (p).

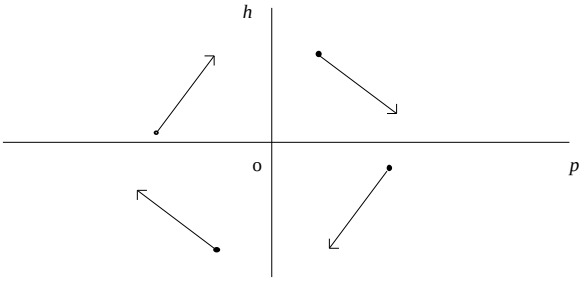
> "We can thus make one point of the plane correspond to the market conditions for a given product, at a given moment; and the development of the market during a certain period will create a curve" (*ibid.*, 28).

So each point represents a market condition on a given date. By connecting these points up according to their position in time, he notes

"immediately upon following this curve in the direction of increasing time, we turn constantly to the right (except for a small exception, which may be due to the inaccuracy of the graph, or to particular circumstances)" (*ibid*.).

In fact, this curve corresponds exactly to the theoretical behaviour of a market and has nothing to do with "chance".

"In fact, in the first quadrant (fig. 17), the profit is positive:



production will therefore tend to increase (at least as long as the profit remains above a certain minimum); but when production exceeds consumption profit will tend to decrease. The representative point will then, in principle, tend to move in the direction of the arrow; and likewise, mutatis mutandis, in the other quadrants" (*ibid*.).

Thus the purpose of this graph was to provide an "empirical" confirmation (based on data drawn from Guillaume's "*cinémogrammes*") of the theoretical behaviour of a market governed by the law of supply and demand. In the case of big profits (increased *h*) the supply reacts by producing more till it exceeds the corresponding demand. As a result, the percentage decreases (decreased *h*) and is accompanied by growing overproduction (increased *p*). Then, in a situation of heavy overproduction, profits, becoming negative, bring about a decrease in overproduction till it becomes negative. So we understand the rotary direction of the graph proposed by Moch. By basing himself on Guillaume's gold market, he noted that it was organised in conformity with the theoretical rotary direction described above. The theoretical description was thus confirmed by the "empirical" development of the market[32].

So we see that the transposition of the methods of classical physics to economics by the members of X-Crise, did not take place without modifications. While the greater part of the mathematics used belongs to classical mechanics, the originality of Potron's application of Frobenius's theorem is without equal. It was one of the first applications of a mathematical theorem to economics that did not use the medium of a physical metaphor. With regard to experiments, developing procedures to test the theories proved more difficult than anticipated. The rare procedures used depend on the use of graphs, even though the members of X-Crise knew the contemporary developments in econometrics. In view of these limits, it is not therefore surprising to see that the economic policy conclusions preached by X-Crise were not deduced from the mathematical models they had, nevertheless, developed.

Conclusion

In conclusion, we would like to emphasise two points.

First of all, even though the members of X-Crise spent the thirties discussing Guillaume's mathematical models, they were hardly used as a reference for the economic policies recommended by this group. Guillaume's studies ended in a call for the development of gold production, but his ideas were still based on liberalism. As for Moch, he called for a centrally planned socialist economy to be put in place. Finally, Potron's observations ended in a statement of impotence. In contrast, X-Crise was to recommend a series of interventionist measures very close to Keynes's theories. This discrepancy probably arose from the theoretical weaknesses of these models, but also from the importance the group accorded to experiments conducted abroad. Thus, the theoretical work, which was, moreover, remarkable for the period, was secondary to the empirical studies that were carried out. The X-Crise engineers were not pure theoreticians, but mainly practitioners or future practitioners of economics.

Therefore, they didn't stop at thinking about the crisis, rather, their ambition was to establish a relevant diagnosis in order to suggest adequate remedies. Even though the members of X-Crise were not necessarily members of the successive governments between 1936 and 1974, their ideas prevailed in the economic policies applied in France, and in the establishment of the institutions that led to the "*trente glorieuses*" (thirty glorious years). Whether we think about the nationalisation of certain key sectors of the French economy (Nicoletis 1967, 21) or the development of subsidised loans and other forms of investment aid (Bauchard 1966, 33), the invention of collective agreements, (Coutrot 1935, 82), the encouragement of trade union development (Nicoletis 1967, 21) or, again, the development of socialisation, in short, "all the modern ideas of French planning were proposed in black and white in 1937" (Bauchard 1966, 35).

Secondly, as we have seen, the formation of X-Crise in the thirties, brought out one aspect of the institutional workings of teaching and research in France at that time. But it also put into perspective another attempt, made forty years later, following the 1974 crisis. In fact, when we think about the "Regulation School" we are struck by the resemblance to X-Crise's constitution. 1/ In both cases we see an intellectual reaction to an unusual economic crisis that France was faced with. 2/ Both groups were largely made up of Polytechniciens. 3/ They grew out of contexts whose main characteristic was a feeling of theoretical and political impotence. The Regulation School grew up when Keynes's theories were proving their inability to deal with the simultaneous occurrence of unemployment and inflation that typified the economic crisis of that time. But the parallel ends there. For, unlike X-Crise, the Regulation School was often criticised for not being able to develop new, alternative economic policies. Perhaps that difference is due to the pragmatism typical of the Polytechnic engineers during the thirties.

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[1] In X-Crise, X is an abbreviation used to identify the Ecole Polytechnique.

[2] Sir Henry Strakosch, commenting on the work of the "Délégation de l'or" of the S.D.N., echoes this: "[t]he appreciation of gold, as expressed in the fall of the general level of commodity prices during the period under review, is popularly being ascribed to "over-production" brougth about in the main - so it is said - by the rationalisation of industries the world over" (quoted by Guillaume 1932, 52). This thesis, expounded by Coutrot, appeared in the deliberations of X-Crise, in November 1931 (Coutrot 1931, 117).

[3] *Le Bulletin du C.P.E.E.* (July 1939, nº 59) was to dedicate an entire number to this recurring theme in X-Crise's works.

[4] These themes were tackled in November 1931 by Coutrot 1931 in X-Crise. They stimulated Nicoletis 1933b, Rueff 1934, Hermant 1935, Tezenas 1935, Branger 1935, Detœuf 1936, Gibrat and Courtot to start a correspondence published in the *Bulletin du C.P.E.E.*, nº 20-21, March - April 1935, appearing in the *Débat sur l'URRS*, nº 29-30, April 1936. Finally we note the appearance of a *bulletin* entirely devoted to the theme of rationalisation (nº 59).

[5] This thesis was clearly stated in a discussion by Vallon of Jacques Branger's paper 1935 where the former affirmed that "given their education, the Polytechniciens cannot refuse to be sympathetic to economic planning. In so doing, we will remain true to the Saint-Simonian tradition, which is already a hundred years old and was the tradition of our great forebears, who founded and gave life to the modern French economy" (Vallon 1935, 17). Moreover, on February 20 1937, an entire meeting of X-Crise was devoted to "Saint-Simonism and the Polytechniciens").

[6] All these theories were presented and discussed in the report on the X-Crise meeting of December 11, 1931 in *X Information*, 12 (7), December 25, 1931: 148-152.

[7] Nicoletis' paper on "the spirit presiding at the formation of the group" of X-Crise testified to this (Nicoletis 1931, 116).

[8] Compaing de la Tour Girard (1931, 119) urged the Polytechniciens to "take on [their] responsibilities. Who committed the first error? The elite, not of today, but of fifty or a hundred years ago, when the intellectual elite had no sense of morality."

[9] Gérard Brun described X-Crise as "an oasis of serenity" allowing a true "socio-political melting pot" where interventionists and liberals could meet (Brun 1982, 21-23).

[10] Here, the reference is to the dominant epistemological idea, as seen in Bardet's remark on the affinity between economic planning and pragmatism (Branger 1935, 12), even if we can find other forms of epistemological reflections among the members of X-Crise. Rueff, for example, seems to have been much more influenced by logical empiricism (Rueff 1922, 6-24).

[11] The reference to Bridgman's operationalism (1927) only appears in the Guillaume brothers' 1937 work (1937, 243), but was already behind their 1932 work. We note in passing that this was the first real reference on this theme in the history of economic thought, before even Schultz and, of course, Samuelson. Finally, there is a very strong similarity between the epistemological and methodological positions of Samuelson' *Foundations* and those of the Guillaume brothers.

[12] See also Ullmo 1937, 9-10.

[13] "Economical thinking " and a minimum of axioms were the two main attributes of "axiomatics" a term that was even used by the Guillaume brothers in 1932 (Guillaume 1932, 63; 1937, 6). Thus the Guillaume brothers prefigured the axiomatics movement in economics in the forties.

[14] The Polytechniciens responded very early to the econometrics project. Rueff was contacted as early as 1929 by its organiser, Ragnar Frisch. Most of the French supporters of this project were Polytechniciens. Among the most active were members of X-Crise like Divisia, Gibrat and Roy. Moreover, Gibrat regularly published "econometric notes" in the *Bulletin du C.P.E.E.* in order to give an account of the progress of these works and also led "a 'study of the economic climate' committee at X-Crise to compensate for the gaps in the Statistique Générale de France" (*ibid*., 110). See Fischman and Lendjel 2000b.

[15] See above on the interpretation of the crisis current in France during the thirties.

[16] Bardet, in one of his first letters, states it clearly: "to sum up, I think we need to take up the question at its beginnings" (Bardet 1931, letter of 25/09/1931, 69).

[17] For a more detailed presentation of the Guillaumes' model, see Fischman and Lendjel 2000a.

[18] We also note that this attention was strongly based on the metaphor of the electrical circuit. Thus, each individual has two "poles": work and demand, producer and consumer. "We will express these facts by stating that these two groups of characters form two poles between which the "value flow", passes with the desired object playing the role of conductor" (Guillaume 1937, 46). In addition, we would point out that, in this context, the Guillaume brothers worked on several metaphors relating to the circuit. Sometimes it was the electric circuit (*idem.*), sometimes the hydraulic circuit (*ibid*., 249-250). Yet, these two metaphors are not interchangeable.

[19] The Guillaumes wrote thus : "[t]he economic freedom of individuals is often a meaningless expression" (Guillaume, 1937, 153).

[20] In China's perpetual *circulus* we are reminded of François Quesnay's ideas.

[21] From 1933, Nicoletis shared this interpretation of the crisis (Nicoletis 1933a, 15-17).

[22] The Guillaumes developed three "small-scale models" in each of their works. We will limit ourselves here to the third, most complete, model.

[23] The Guillaumes' simplified model describes a two-sector economy.

[24] Nicoletis 1933b, following Boris 1932, introduced Keynes's theories to France.

[25] For a presentation of Moch's model, see Fischman and Lendjel 1999.

[26] Potron wrote few articles on the same topic, as soon as 1911 (Potron [1911a], [1911b]). For a more complete presentation of Potron's economics and biography, see Abraham-Frois and Lendjel [2001].

[27] For a reprint of Potron's 1935 article, see Lendjel [2000].

[28] Gibrat's lecture referred to by Potron was not published in the *Bulletin du C.P.E.E.*

[29] Nevertheless, X-Crise didn't escape from the famous debate "for or against mathematical economics". Academics like Pirou 1937, Darmois 1937 and Halbwachs 1937, Polytechniciens like Ullmo 1937, Coutrot (discussing Pirou 1937 and Darmois 1937), or Divisia 1938 joined the bitter battle and the discussion following Roy's paper in the November 1938 bulletin (*Bulletin du C.P.E.E.*, nº. 51, pp. 17-21) mobilised Nogaro, Lacoin, Delaisi and also Sauvy. See Fischman and Lendjel 2000c.

[30] We note the sometimes approximate precision of Moch and the Guillaume brothers' notations. Indeed, the Guillaume brothers were to be severely criticised by Divisia on this point: "the authors seem to us not to escape a fairly general mistake made by those using mathematics: starting from "very simple" premises and introducing, more or less explicitly, other hypotheses or assertions along the way" (Divisia 1938, 193).

[31] See Fischman and Lendjel 1999.

[32] Nevertheless, we note that the "data" Moch based himself on assumed that one can measure the difference between a sale price and a production cost and, above all, the gap between production and consumption.